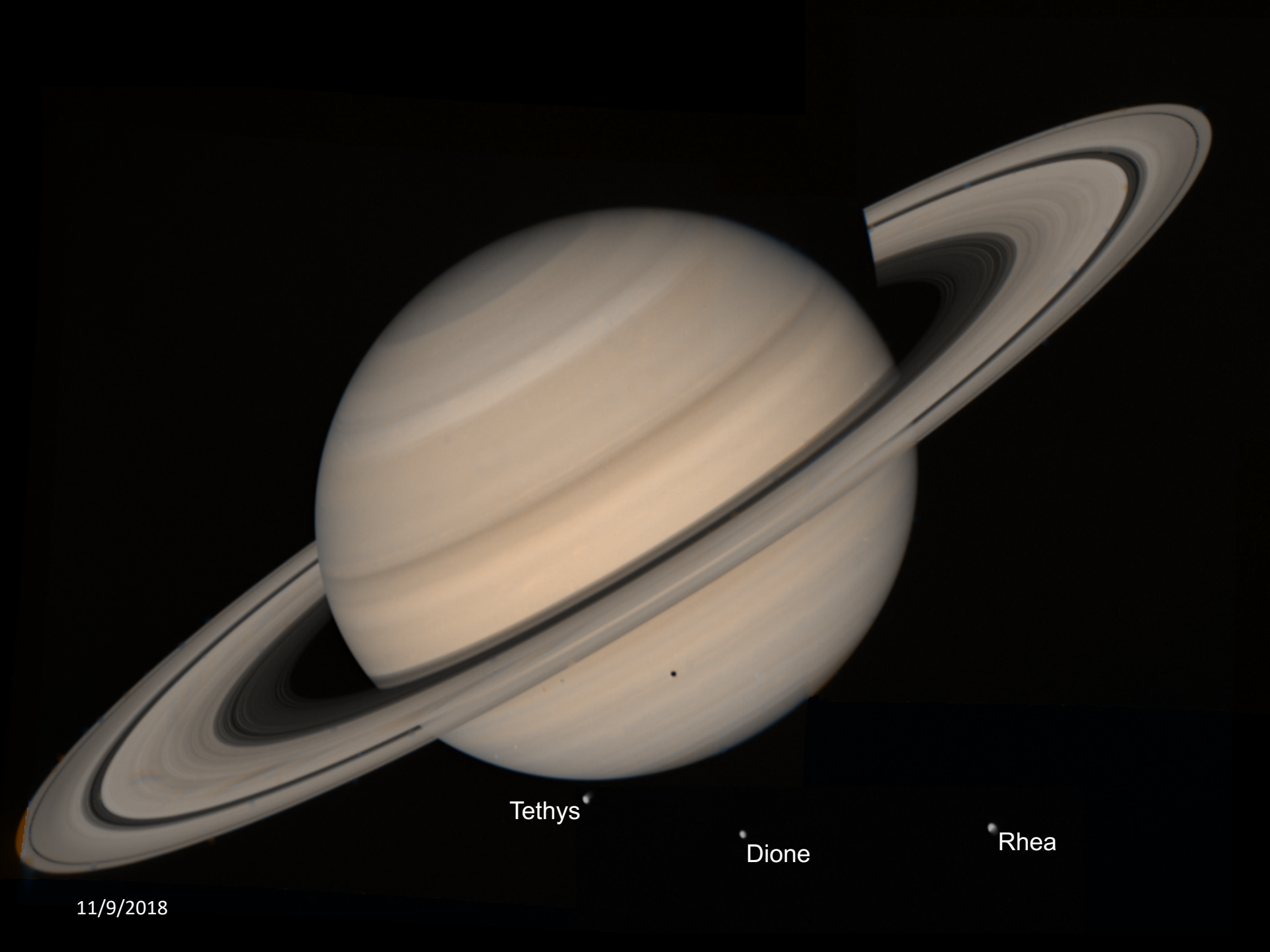


# Return to Saturn: Future Saturn Entry Probe Mission Concepts



Dr. David H. Atkinson, Senior Systems Engineer  
Jet Propulsion Laboratory  
November 9, 2018



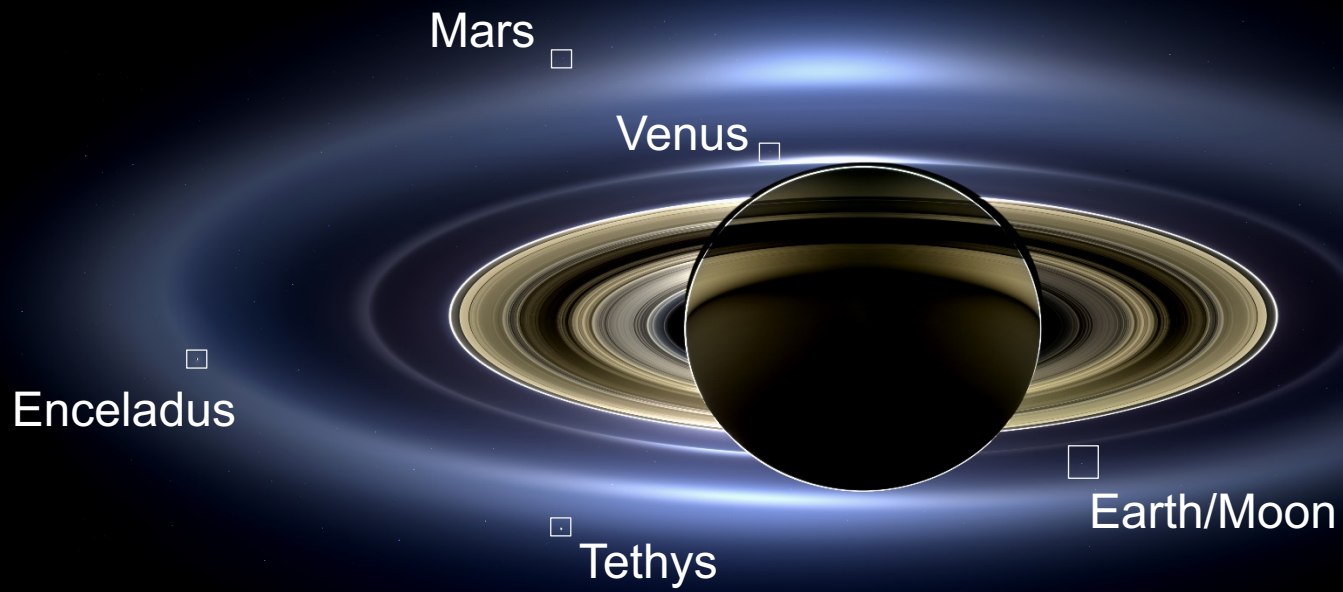
Tethys

Dione

Rhea

11/9/2018





# Science Justification for Exploring Giant Planets

**Comparative planetology** of well-mixed atmospheres of the outer planets is key to the **origin and evolution of the Solar System**, and, by extension, Extrasolar Systems.

Atreya, S. K. et al., “Multiprobe exploration of the giant planets – Shallow probes”, Proceedings of the 3rd International Planetary Probes Workshop, Anavyssos, Greece, 2005.

There is only one Rosetta Stone in the solar system and it's in the British Museum. We cannot hope to understand the big problems of **origin and evolution** by studying only one planet or one comet. Indeed, we must be able to make **comparative** studies even to understand a single planet. Thus our strong need to improve our knowledge of Jupiter is inextricably coupled to the necessity to achieve a comparable understanding of Saturn, Uranus and Neptune.

Owen, T., “Atmospheric Entry Probes: Needs and Prospects”, Proceedings of the 1<sup>st</sup> International Planetary Probes Workshop, Lisbon, 2003.

# Background

- The giant planets in our solar system contain clues to the origin of the planets and the conditions that set up terrestrial planet formation.
  - Giant planets will also be key to also understanding exoplanet systems.
- Comparative study of Jovian and Saturnian composition and structure maps gradients in time and space in our protoplanetary disk.
  - Jupiter will be well studied after Galileo/Juno, but which of its features (core size, circulation, etc.) are unique vs universal?
  - Cassini will leave remaining knowledge gaps about Saturn that require *in situ* sampling and are needed to fit into the puzzle of solar system formation.



# Key Questions



How did the solar system form?

What role did the giant planets play in promoting habitable planets?

What can be learned about exoplanets from the giant planets?

# Decadal Survey Saturn Probe

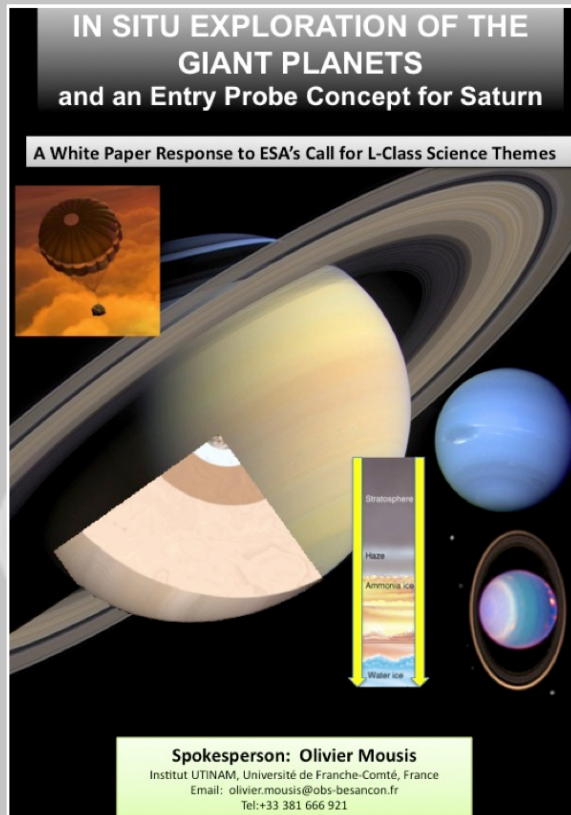
## *PSDS Highest Priority Science Objectives*

1. Determine the noble gas abundances and isotopic ratios of H, C, N, and O in Saturn's atmosphere.
2. Determine the atmospheric structure at the probe descent location.

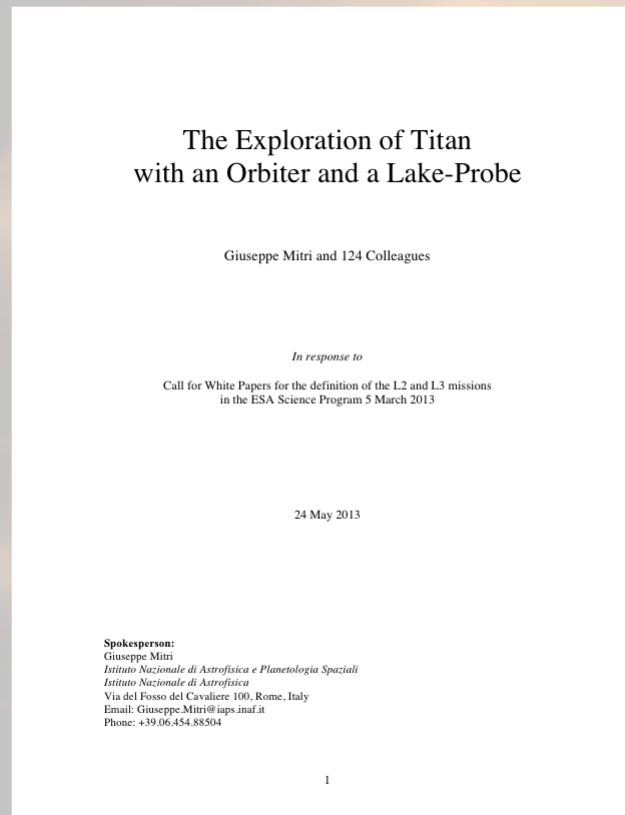
## *PSDS Lower Priority Science Objectives*

1. Determine the vertical profile of zonal winds as a function of depth at the probe descent location(s).
2. Determine the location, density, and composition of clouds as a function of depth in the atmosphere.
3. Determine the variability of atmospheric structure and presence of clouds in two locations.
4. Determine the vertical water abundance profile at the probe descent location(s).
5. Determine precision isotope measurements for light elements such as S, N, and O found in simple atmospheric constituents.

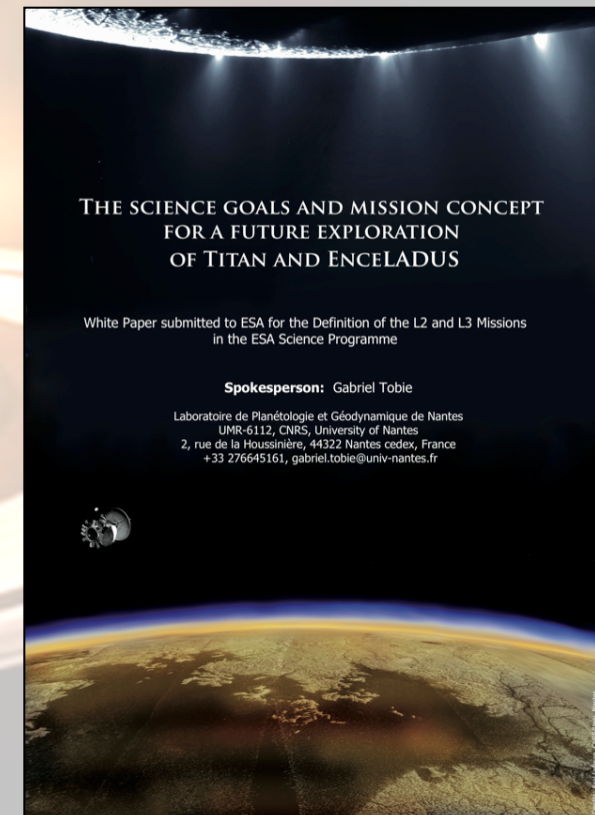
# International Interest in Saturn System



O. Mouis (FR) & L. Fletcher (GB)



G. Mitri (IT)



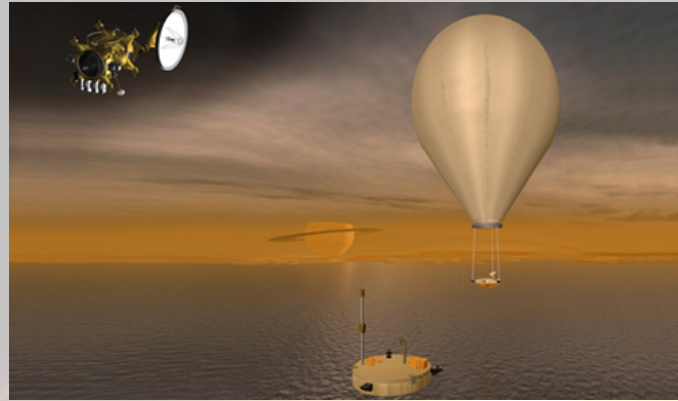
G. Tobie (FR) & N. Teanby (GB)



# International Interest in Saturn System



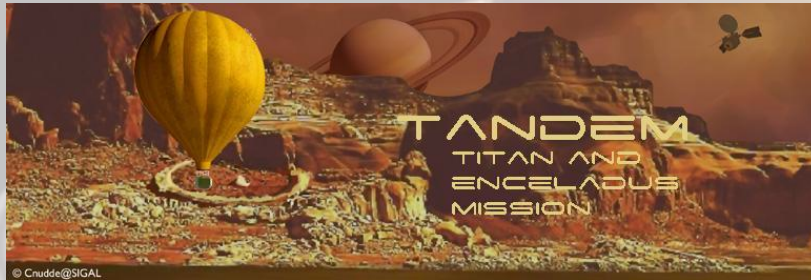
**Titan Explorer**  
*NASA Flagship study (2007)*



**Titan and Saturn System Mission (TSSM)**  
*ESA-NASA joint mission study (2008)*



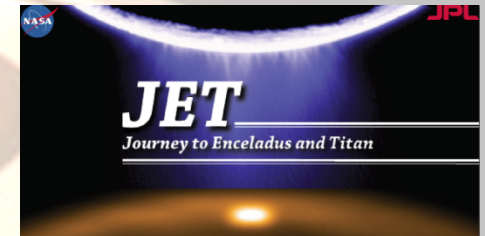
**Titan Mare Explorer (TiME)**  
*NASA Discovery candidate (2008-12)*



**Titan and Enceladus Mission (TandEM)**  
*ESA L1-CV candidate (2007)*



**Titan Aerial Explorer (TAE)**  
*ESA M3-CV candidate (2010)*



**Journey to Enceladus & Titan (JET)**  
*NASA Discovery candidate (2010)*



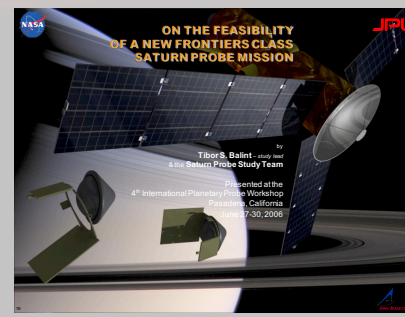
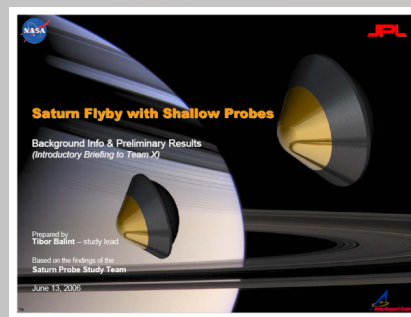
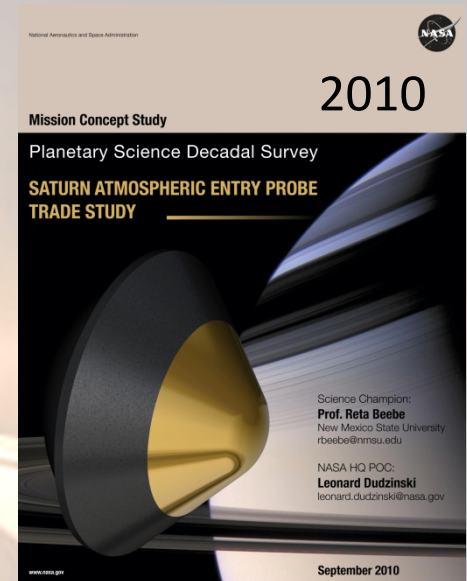
**KRONOS Saturn**  
*ESA L1-CV candidate (2007)*

A variety of mission concepts to explore the Saturn system after Cassini-Huygens. The Saturn system is ideal for *in situ* explorations.



**AVIATR: Aerial Vehicle for In Situ and Airborne Reconnaissance**  
*NASA Discovery candidate (2010)*

# Saturn Probes: A Well Studied Problem



Exp. Astron. (2009) 23:947–976  
 DOI 10.1007/s10666-008-9094-9

ORIGINAL ARTICLE

**Kronos: exploring the depths of Saturn with probes and remote sensing through an international mission**

R. Marty · T. Guillot · A. Coustenis ·  
 the Kronos consortium · N. Achilleos · Y. Albert ·  
 S. Asmar · D. Atkinson · S. Atreya · G. Babasides ·  
 K. Balme · T. Balint · B. Banfield · S. Barber ·  
 B. Bézard · G. L. Björkr · M. Blanc · S. Bolton ·  
 N. Chanover · S. Charoz · E. Chassefière ·  
 J. E. Colwell · E. Deangeli · M. Dougherty ·  
 P. Drossart · E. M. Flasar · T. Fouchet ·  
 R. Frampton · I. Franchi · D. Gautier · L. Gurvits ·  
 R. Hueso · B. Kazeminejad · T. Krimigis ·  
 A. Jambon · G. Jones · Y. Langevin · M. Lese ·  
 E. Lellouch · J. Lunine · A. Millio · P. Vlahakis ·  
 B. Mank · A. Morse · M. Moreira · X. Moussas ·  
 C. Murray · I. Mueller-Wodarg · T. C. Owen ·  
 S. Pogresny · R. Prange · P. Read ·  
 A. Sanchez-Lavega · P. Sarda · D. Stam · G. Tinetti ·  
 P. Zarke · J. Zarnecki

Received: 7 December 2007 / Accepted: 2 April 2008 / Published online: 13 May 2008  
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**Abstract** *Kronos* is a mission aimed to measure in situ the chemical and isotopic compositions of the Saturnian atmosphere with two probes and also by remote sensing, in order to understand the origin, formation, and evolution of giant planets in general, including extrasolar planets. The abundances of noble gases, hydrogen,

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 A. Coustenis  
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2009 Springer



**NASA TECHNICAL  
MEMORANDUM**



**N73-30800  
NASA TM X-2824**

**NASA TM X-2824**

**CASE FILE  
COPY**

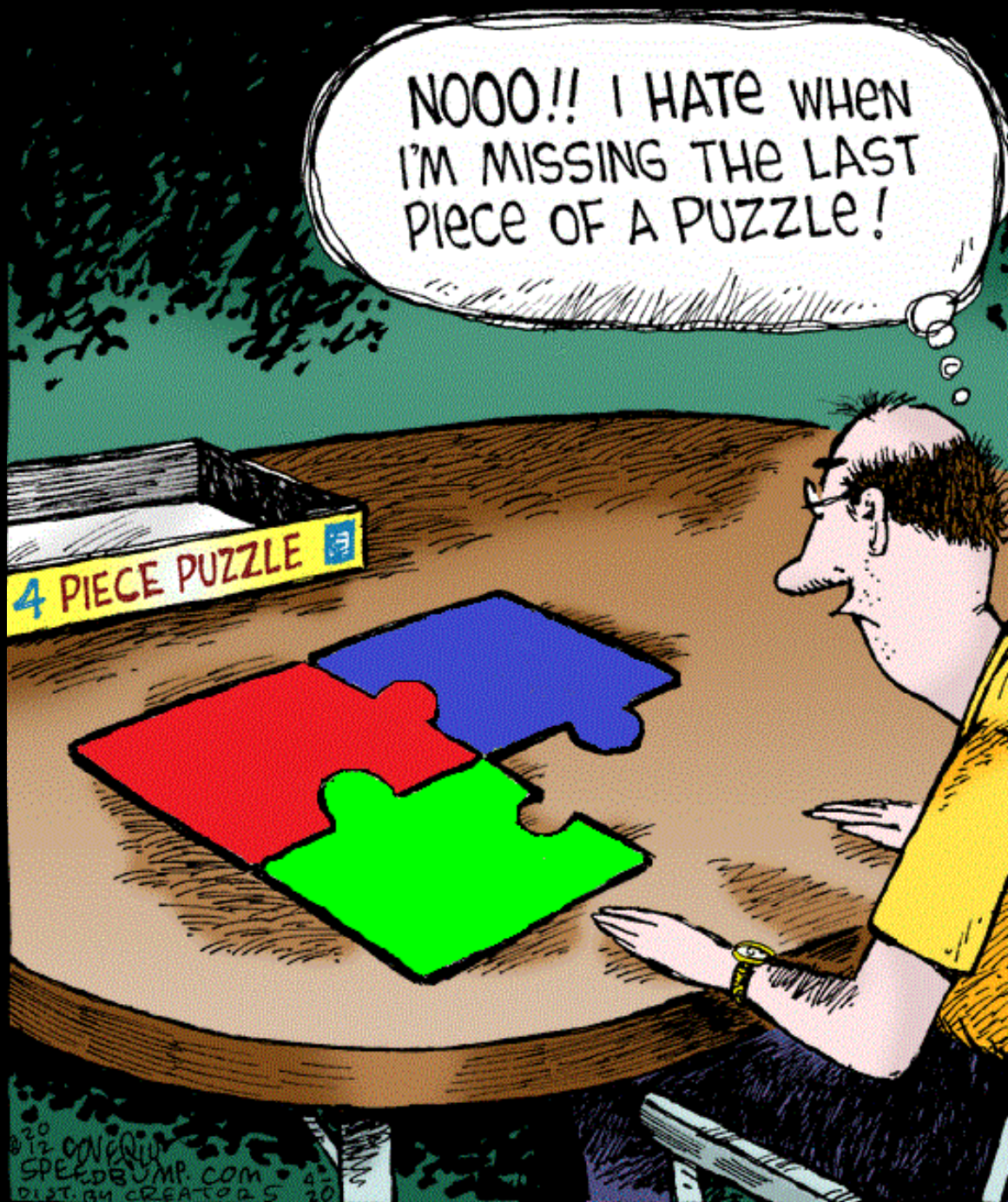
**MISSION PLANNING FOR  
PIONEER SATURN/URANUS  
ATMOSPHERIC PROBE MISSIONS**

*by Byron L. Swenson, Edward L. Tindle,  
and Larry A. Manning*

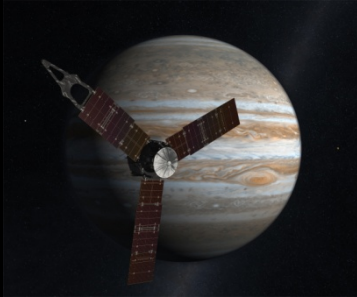
*Ames Research Center  
Moffett Field, Calif. 94035*

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1973**





# How does Saturn Fit?

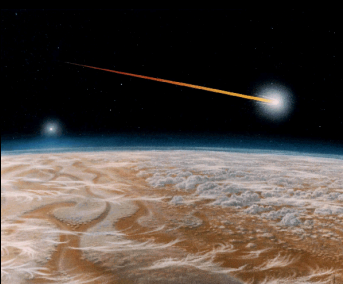
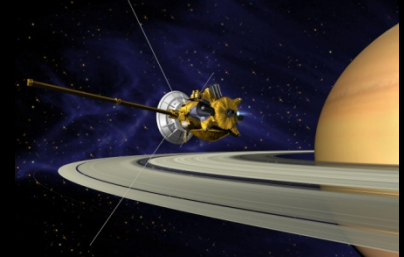


Jupiter Internal  
Structure

**Juno (2016- )**

Saturn Internal  
Structure

**Cassini  
Proximal Orbits  
(2017)**



Jupiter  
Atmospheric  
Composition

**Galileo Probe  
(1995)**

Saturn  
Atmospheric  
Composition  
**Saturn Probe**



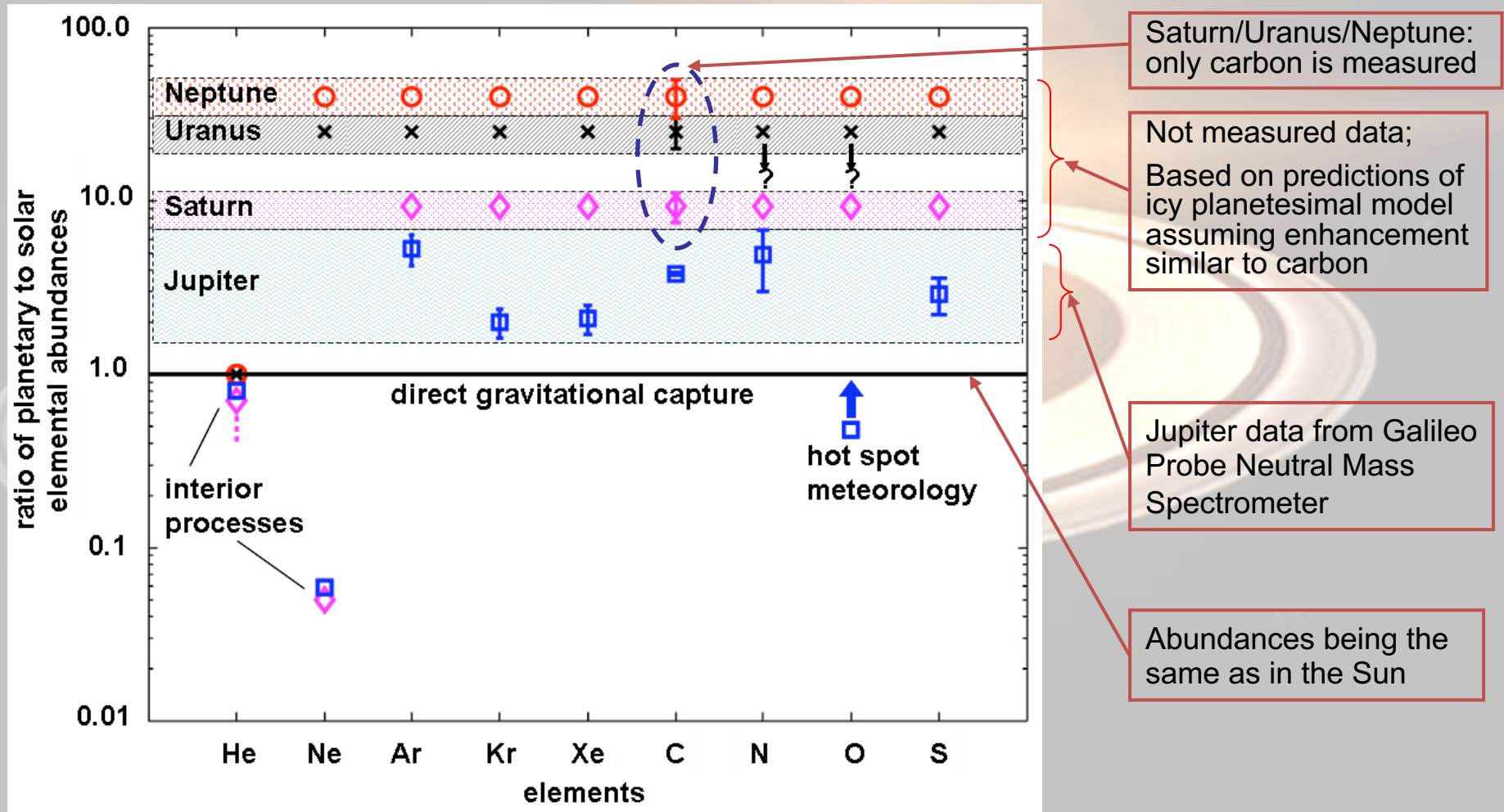
# What can we learn from Saturn?





# Background

## Heavy Elemental Abundances of the Giant Planets (Relative to H in the atmospheres of the Giant Planets)



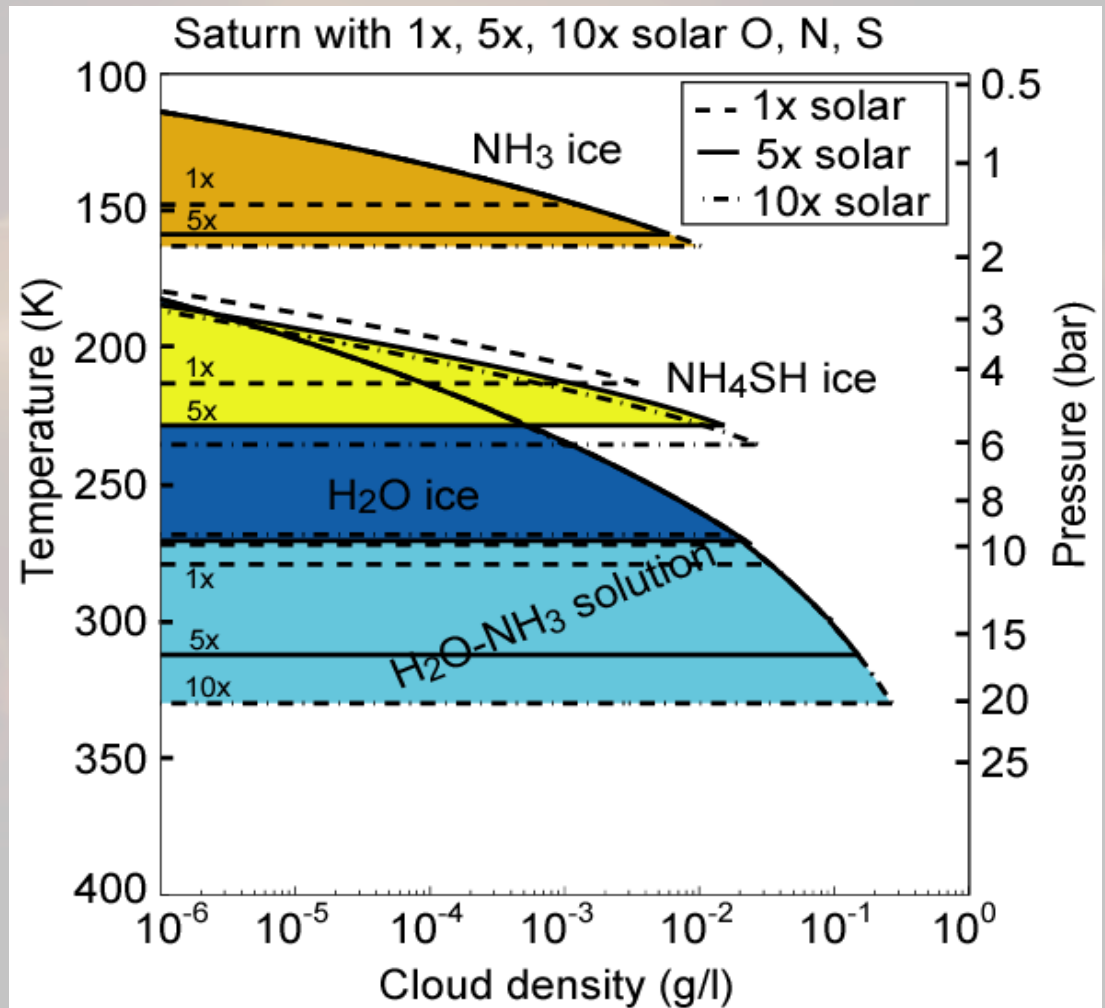
# Predicted Saturn Clouds

Liquid water clouds (or possibly water-ammonia solution clouds) are lowest altitude clouds in Saturn's atmosphere.

Base of cloud is expected at 10-20 bars, but could be as deep as 45 bars.

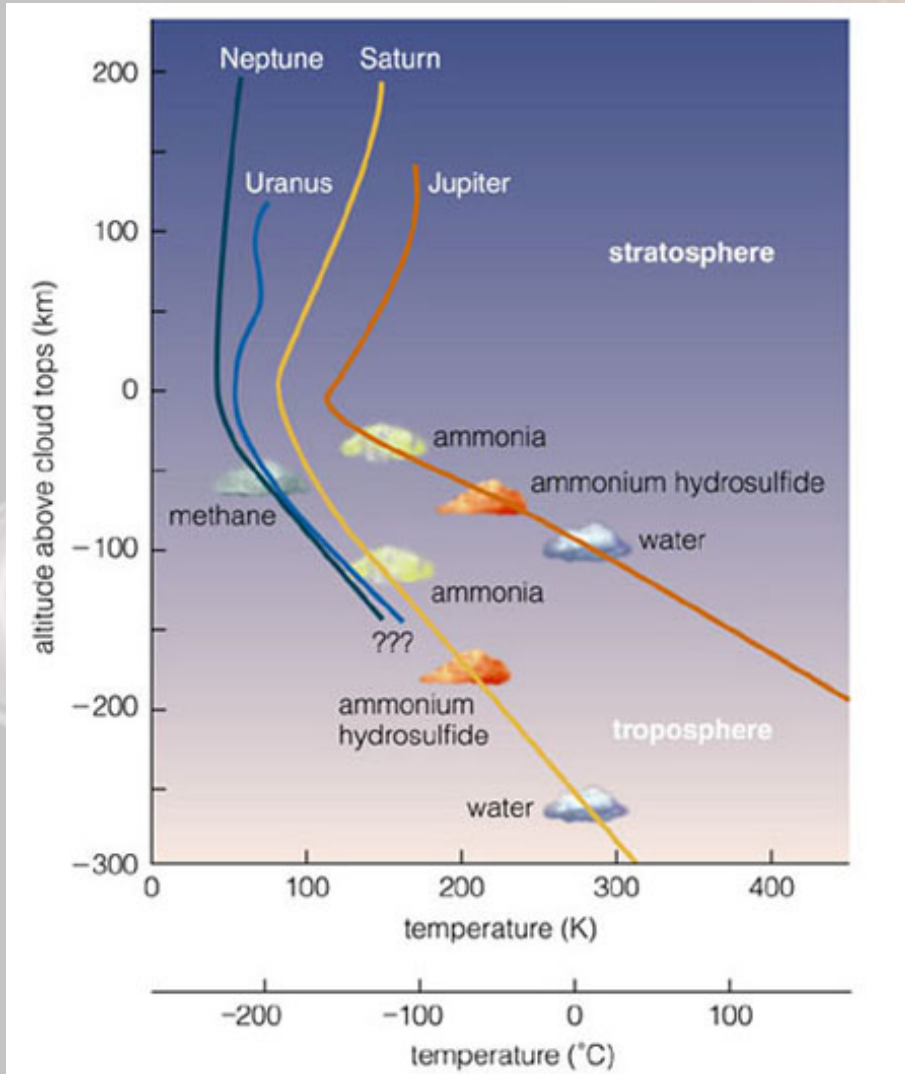
A 10 or 20-bar probe won't get to well-mixed H<sub>2</sub>O region.

Use disequilibrium species to estimate deep water.



Ref: Sushil Atreya, "SATURN PROBES: Why, Where, How?", International Planetary Probe Workshop, IPPW-4, Pasadena, California, June 2006.

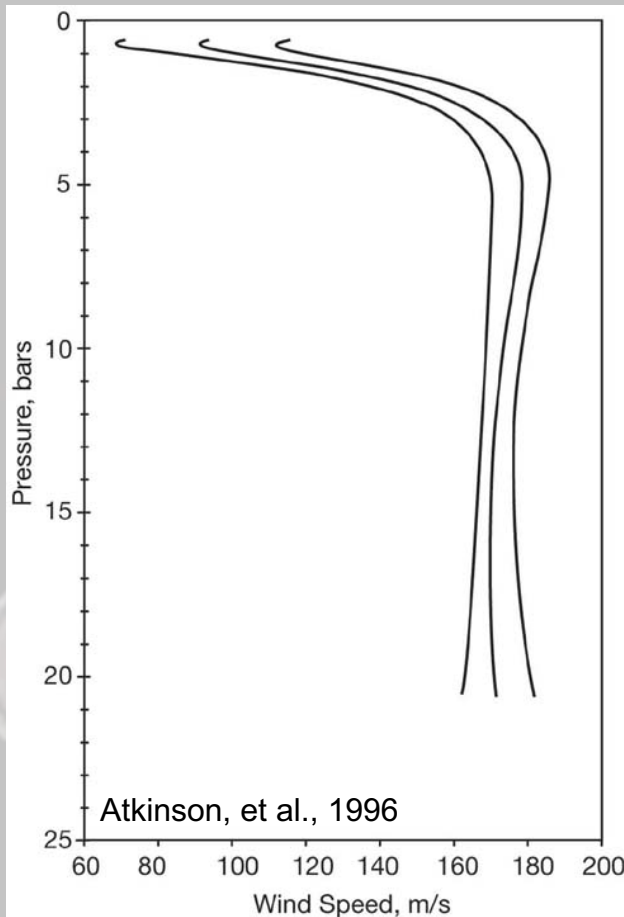
# Radiation Balance and Clouds



- Remote sensing provides some constraints on cloud structure, but relies heavily on assumptions.
- A probe provides ground truth, connection to observed cloud top motions.
- *In situ* measurements of pressure/temp can determine atmosphere wet vs dry adiabat.

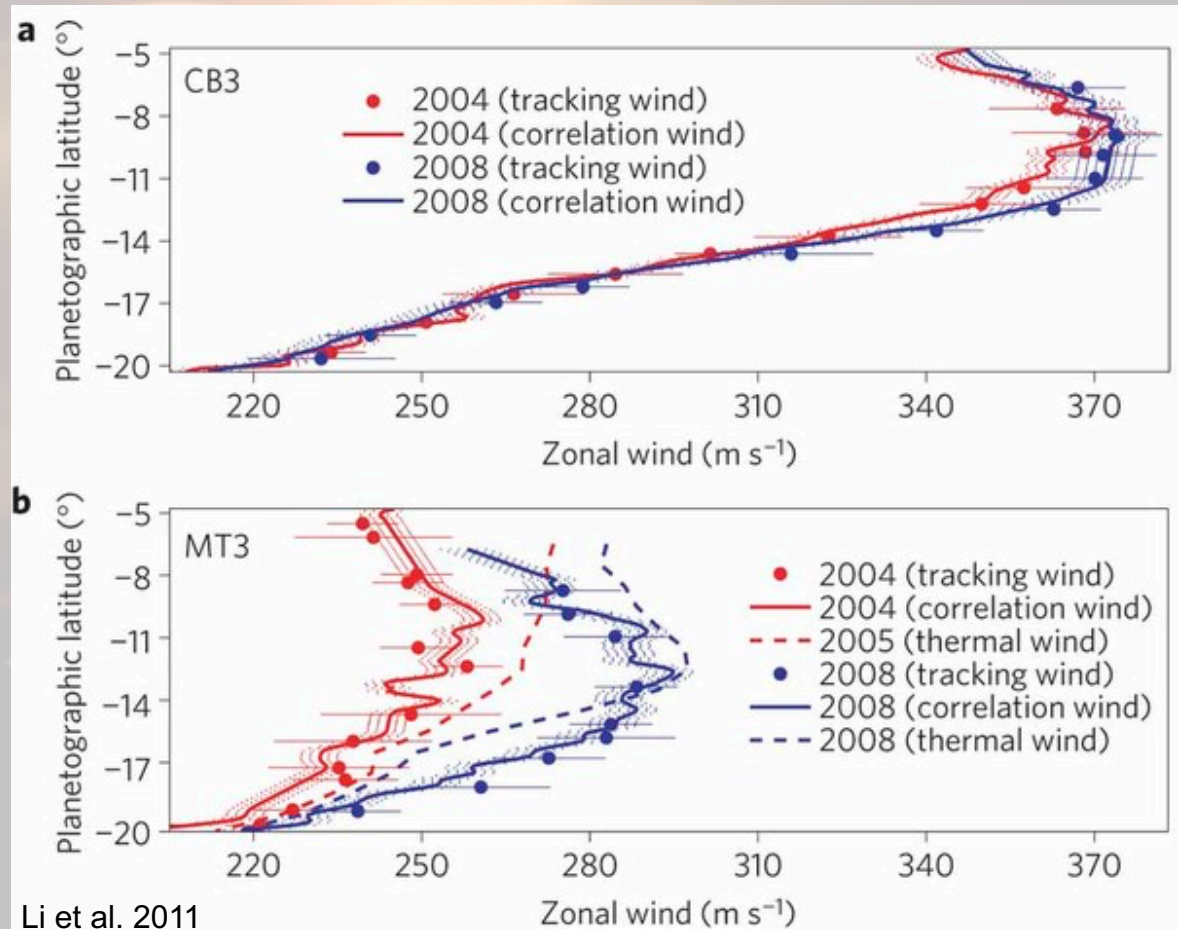


# Winds and Waves



Galileo Probe showed winds increasing with depth, with evidence of gravity waves in Jupiter's atmosphere.

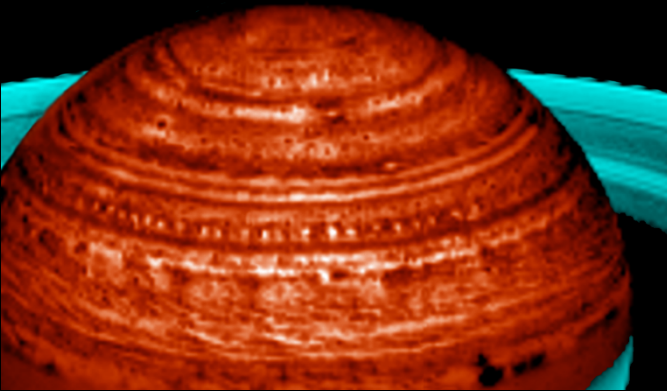
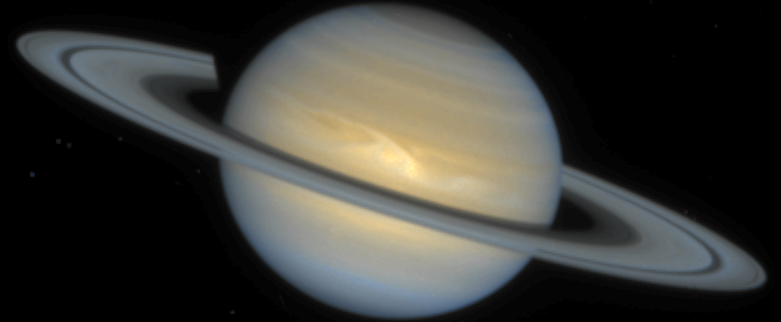
Saturn's winds vary with latitude over time and altitude.



Li et al. 2011

# Goals for Saturn Science

**Origin and Evolution** Saturn atmospheric composition (C, S, N, O, He, Ne, Ar, Kr, Xe) and ratios of key isotopes (e.g., D/H,  $^{15}\text{N}/^{14}\text{N}$ ,  $^3\text{He}/^4\text{He}$  and other noble gas isotopes) relative to solar and Jupiter.



**Planetary Processes** Global circulation, winds, weather, and interior processes (e.g., by measuring disequilibrium species such as  $\text{PH}_3$ ,  $\text{CO}$ ,  $\text{AsH}_3$ ,  $\text{GeH}_4$ ,  $\text{SiH}_4$ ).

# Saturn Entry Probe Science Objectives

## Measured to 10 bars

### Tier 1 Objectives

- Composition
  - Abundances of noble gases He, Ne, Ar, Kr, and Xe (*and isotopes!*)
  - Isotopic ratios of H, C, N, and O
  - **Desired:** Measurements of disequilibrium / diagnostic species such as CO, PH<sub>3</sub>, AsH<sub>3</sub>, SiH<sub>4</sub>, GeH<sub>4</sub>
- Atmospheric structure (Pressure & Temperature vs. depth)

### Tier 2 Objectives

- Vertical profile of east-west winds at the probe entry location
- Location, density, and composition of clouds as a function of depth
- Vertical profile of water abundance at the probe descent location
- Variability of atmospheric structure and clouds in two locations



# Instrument Suite - Galileo Probe

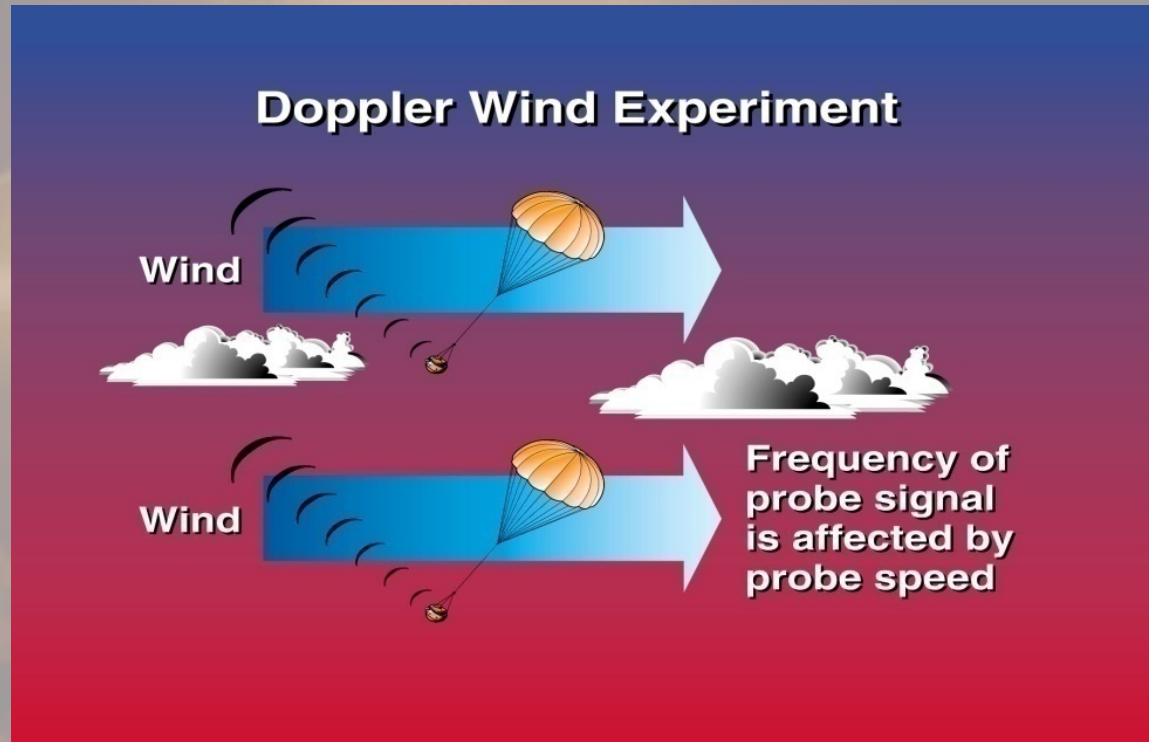
Instrument	Mass	Power	Bit rate	Volume	Special Acc. Requirements
<u>Atmosphere structure instrument (ASI)</u>	4.0 kg	6.3 W	18 bps	3100 cm <sup>3</sup>	Pressure inlet port; temperature sensor outside boundary layer; 12,408 bits storage
<u>Nephelometer (NEP)</u>	4.8 kg	13.5 W	10 bps	3000 cm <sup>3</sup>	Free-stream flow through sample volume; 800 bits data storage; pyro for sensor deployment
Helium abundance detector (HAD)	1.4 kg	1.1 W	4 bps	2400 cm <sup>3</sup>	Sample inlet port
<u>Net flux radiometer</u>	3.0 kg	10.0 W	16 bps	3500 cm <sup>3</sup>	Unobstructed view 60° cone +/-45° with respect to horizontal
<u>Neutral mass spectrometer (NMS)</u>	12.3 kg	29.3 W	32 bps	9400 cm <sup>3</sup>	Sample inlet port at stagnation point
Lighting and radio emission detector/energetic particle detector (LRD/EPI)	2.5 kg	2.3 W	8 bps	3000 cm <sup>3</sup>	Unobstructed 4P Sr FOV; RF transparent section of aft cover, 78° full cone view at 41° to spin axis
<b>Total</b>	<b>28 kg</b>	<b>62.5 W</b>	<b>128 bps<sup>+</sup></b>	<b>24,400 cm<sup>3</sup></b>	

An example of a “focused” Instrument suite that addresses a subset of critical science measurements would only include those underlined in red.

# Doppler Wind Experiment

## Measurements:

- Zonal winds, waves, turbulence
- Probe dynamics (spin, aerodynamic buffeting, pendulum motion, etc.)



Heritage: Galileo (D. Atkinson, Univ. Idaho & J. Pollack, NASA Ames)  
Huygens (M. Bird, Univ. Bonn)

# Previous Trade Elements & Decision Drivers

Mission Class (*key study driver*)

Launch vehicle (*lower cost*)

Trajectory (*target mission timeframe*)

Launch opportunity (*mission timeframe*)

Architecture (*lower cost*)

Approach (*comm, TPS*)

Number of probes (*science*)

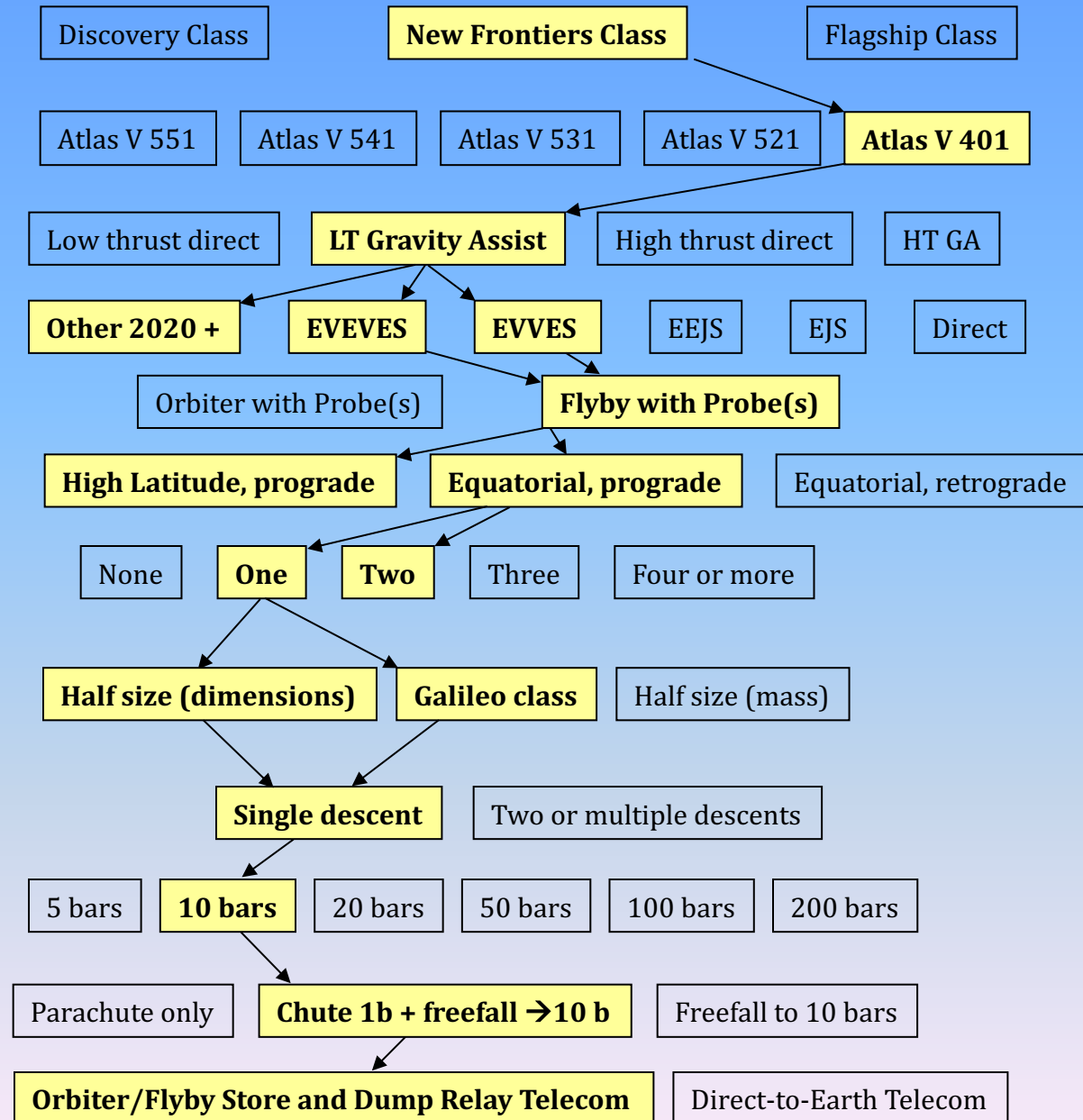
Probe size (*heritage*)

Descent module(s) (*simplicity*)

Descent depth (*science*)

Descent mode (*visibility, comm, extr.env*)

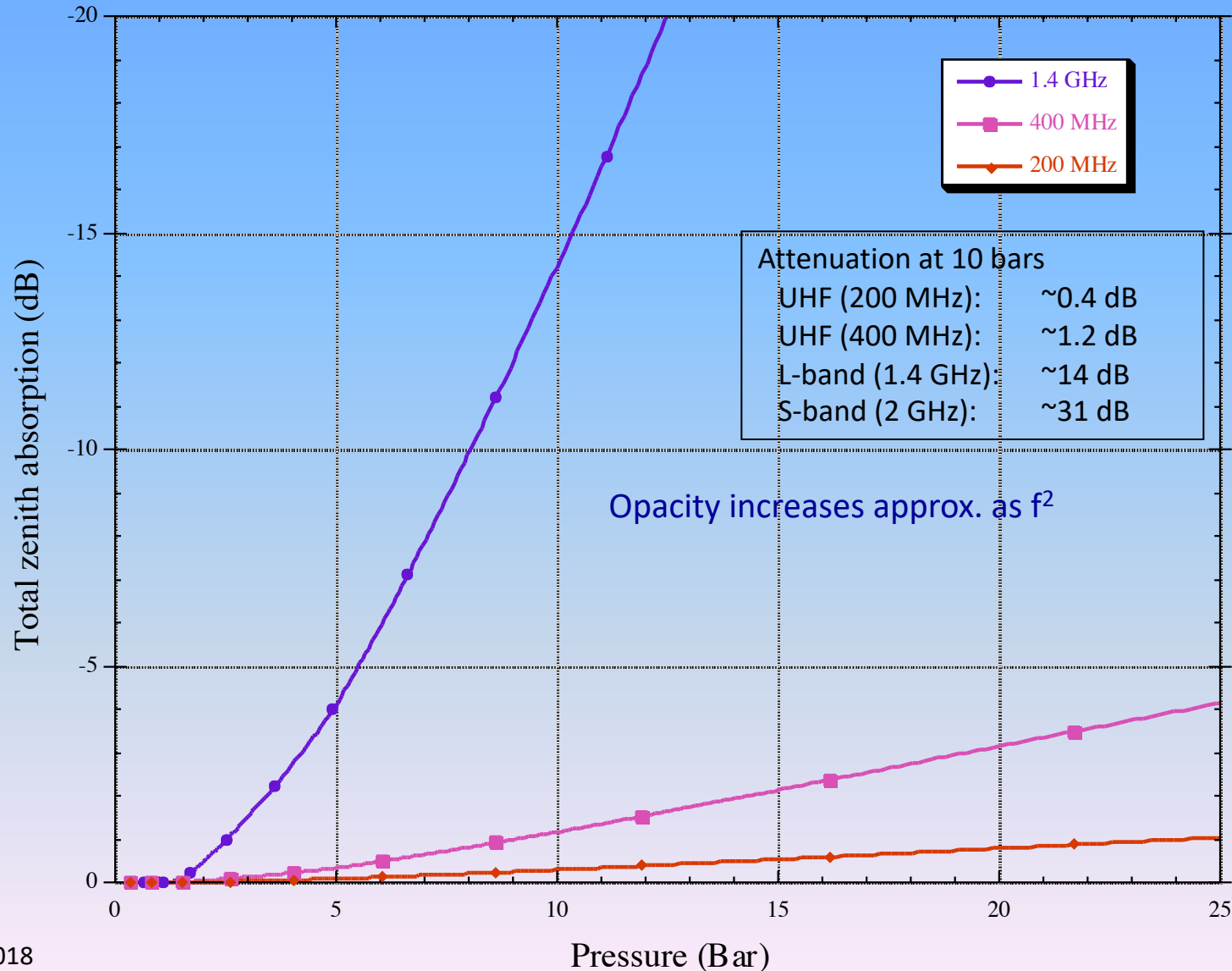
Telecom Architecture (*physics*)






# Zenith Attenuation Based on Ammonia at 10x Solar Abundances

Attenuation vs Pressure for Several Radio Frequencies



# Saturn Probe Interior and aTmospheric Explorer / SPRITE



➤ JPL/GSFC/Ames SPRITE mission proposed to NASA New Frontiers 4 call. Phase A selections due Nov-Jan.

➤ SPRITE Team:

Principal Investigator: A. Simon (GSFC)

Deputy PI: D. Banfield (Cornell)

Project Scientist: D. Atkinson (JPL)

Mission management: JPL

Partners: NASA Ames, Langley, and Goddard

# European Hera Saturn Probe

- European Hera Saturn probe mission proposed to European Space Agency Medium Class mission program M5.

First down select (Technical Review): 30 proposals → 11 proposals.

Project interviews at ESTEC on November 7.

Phase A selections expected in Spring, 2018.

- Hera Team:

Proposal Lead: O. Mousis (Lab for Astrophys., Marseilles)

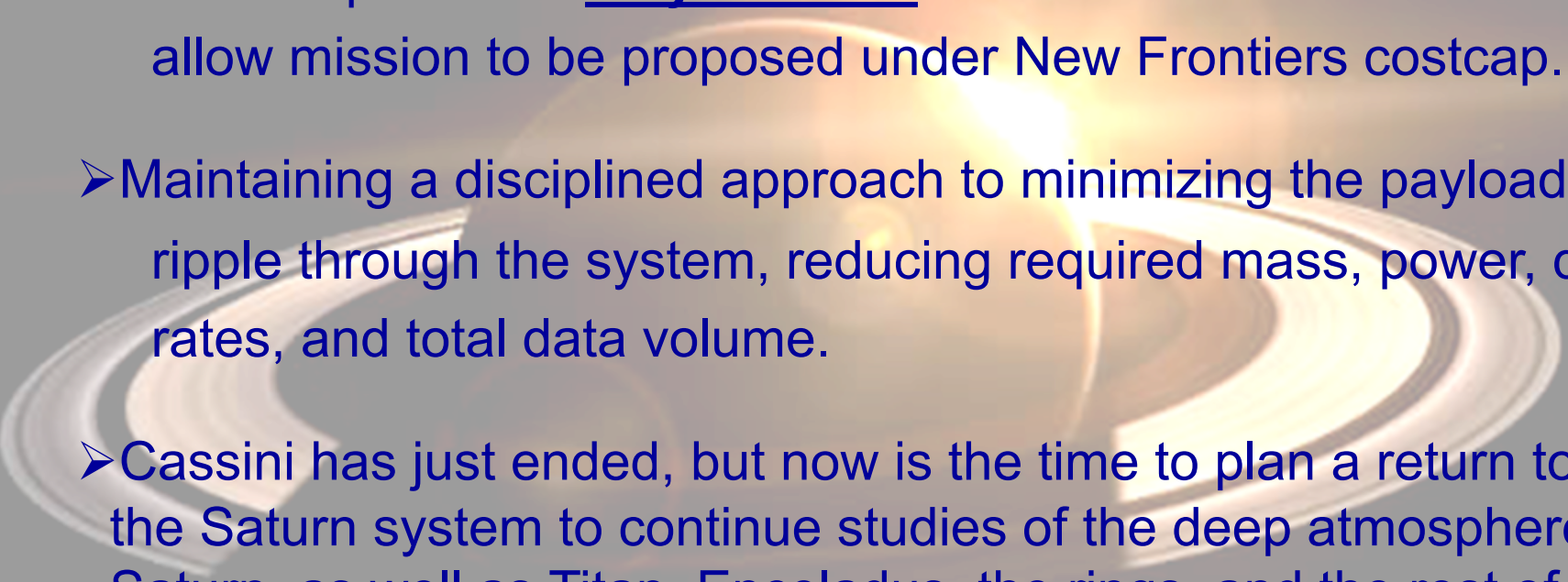
Deputy Lead: D. Atkinson (JPL)

Industry Partner: Airbus (Toulouse)

Instrument providers: Switzerland, Italy, The Netherlands, USA.



# Conclusion

- 
- Critical, high-priority science at Saturn can be accomplished with shallow probes. A **very focused** set of measurements should allow mission to be proposed under New Frontiers costcap.
  - Maintaining a disciplined approach to minimizing the payload will ripple through the system, reducing required mass, power, data rates, and total data volume.
  - Cassini has just ended, but now is the time to plan a return to the Saturn system to continue studies of the deep atmosphere of Saturn, as well as Titan, Enceladus, the rings, and the rest of the Saturn system.

**Comparative planetology** of well-mixed atmospheres of the outer planets is key to the origin and evolution of the **Solar System**, and, by extension, **Extrasolar Systems**.

Atreya, S. K. et al., "Multiprobe exploration of the giant planets – Shallow probes", *Proceedings of the 3rd International Planetary Probe Workshop, Anavyssos, Greece, 2005.*

